INNOVATIVE GAS LIQUEFACTION CONCEPT
The Solution for the Associated Gas Problem

Introduction
Stork Engineers & Contractors (STORK) and CRYENCO have joined forces to further develop a novel technology for the liquefaction of gases.

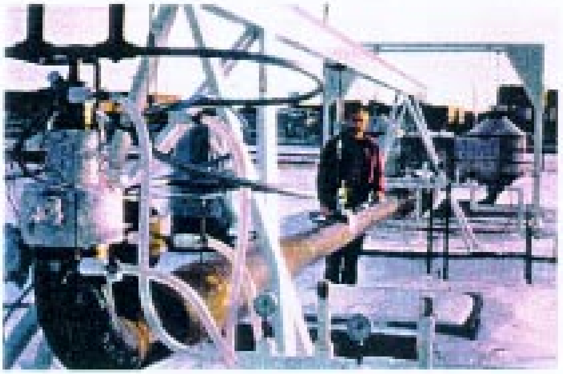
This technology uses thermoacoustic energy to potentially achieve temperatures as low as -200 deg.C, making it particularly suitable for the liquefaction of natural gas, as well as for liquefaction of various other industrial gases. The technology is called TADOPTR, an acronym for Thermoacoustically Driven Orifice Pulse Tube Refrigerator.

The technology has the potential to become a winning solution for the well-known associated gas problem that the Oil and Gas industry now faces. And that is because the technology is very simple, reliable, cost effective, and because it has no moving parts at all. These factors mean that the technology has a strong advantage over other gas conversion technologies, especially offshore or in remote locations.

The technology has been under development with Los Alamos National Laboratory (LANL), with strong support from the USDOE Federal Energy Technology Center.

STORK and CRYENCO are working together with LANL to further develop the technology to a size suitable for relatively large-scale applications. CRYENCO will fabricate the equipment, and will market the technology outside the Oil and Gas industry. LANL will continue to provide fundamental research, whereas STORK intends to market the liquefaction concept for the Oil and Gas industry, for which it has acquired the worldwide exclusive license rights for larger capacities.

Technology and Performance
The TADOPTR technology is essentially a cooling machine based on a modified Stirling refrigeration cycle (the OPTR side), except that the working gas that achieves the cooling is not displaced and (de)compressed by means of pistons, but by means of acoustic wave power. The working gas is Helium. The acoustic power is simply generated by imposing a steep temperature gradient across a specially designed heat exchanger called the stack at the other side of the apparatus, which causes the working gas to vibrate (the TAD side). The acoustic energy is transferred from the TAD to the OPTR via the so-called resonator. The length of the resonator determines the oscillation frequency of the standing wave. The TADOPTR design presently under development uses a frequency of approx. 40 Hz.



The TADOPTR has no moving parts whatsoever. The TADOPTR only needs fuel gas for heating the TAD side of the apparatus, and a suitable cooling medium (e.g. water) to serve as a heat sink for the TAD and for the cooling machine (the OPTR).

The Development Program
The TADOPTR technology needs further development until it is suitable for relatively large-scale applications (i.e. cooling capacities of several hundreds of Kilowatts or more). The status of the development is such however, that there is a large degree of confidence that further scale-up and efficiency improvement will be feasible within a reasonable time scale, e.g. 3-4 years. For relatively small units, e.g. up to approx. 150 Kilowatts, first commercial application could be within 2-3 years. The underlying thermodynamic and physical phenomena are well enough understood to enable prediction of large unit performances.

The main challenges during the further development will be in the engineering and product development areas.

The expected efficiency of the next prototype TADOPTR, a 500 gpd unit (based on natural gas liquefaction), will be to liquefy 70%/burn 30%, which is a leap step improvement compared with the performance of the 140 gpd unit with a fuel efficiency of 40% which was successfully tested during 1998 (photo), indicating that there is room for further improvement.

The aim of the development program is to further improve the fuel efficiency to approx. 85%/15%, and to scale up the apparatus to a cooling capacity of at least 40,000 gpd LNG, and preferably larger.

Potential Markets

The TADOPTR technology will be particularly attractive at locations where reliability, minimum maintenance, ease of operation and the availability of a simple form of external energy source, are of prime importance.

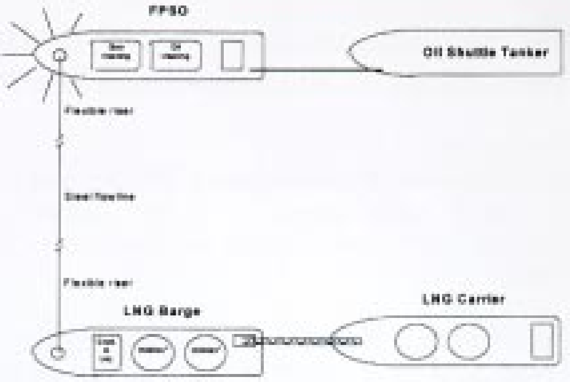
Typical markets of interest will be the offshore oil and gas industry, remote onshore locations for small-scale domestic gas supply, liquefaction of industrial gases, remote onshore oil field developments, peak shaving units for pipeline gas supply, boil-off reliquefaction units, e.g. on methane carriers or on mobile transportation equipment, etc.etc.

For the offshore market, STORK has started the development of an offshore liquefaction plant concept.

The Offshore Liquefaction Concept

To demonstrate the potential that this technology has for offshore use in remote locations, a preliminary concept is being developed by STORK that demonstrates that small-scale offshore natural gas liquefaction may be economically feasible.

This concept is based on an operating scenario, where the associated gas from an oil producing FPSO is pre-treated and dehydrated on the same FPSO. From there the clean gas is transferred to a permanently moored separate LNG liquefaction and storage vessel or barge , via low pressure subsea risers and a flowline.



On the LNG vessel, the gas is liquefied using TADOPTRS. A portion of the natural gas is used for the TADOPTR burners. An indirect sea water cooled cooling water system is used for heat removal. The liquefied natural gas (LNG) is then stored. Unloading takes place every 2-3 weeks using a relatively small LNG shuttle carrier.

The concept economics include all extra costs for the liquefaction process, such as gas pre-treatment, liquefaction, risers, flowline, LNG vessel including its mooring, and LNG offloading. LNG transport to shore is excluded.

A cost-effective variation to this concept is a scenario where the LNG liquefaction and storage is integrated on the oil producing FPSO. Such a scenario may be particularly interesting for Early Production Systems and for certain drilling vessels.

For both scenario's refer to table 1 for the parameters used and the results.

Table 1 - Offshore Liquefaction Concept		
Parameters used for Scenario's		
Liquefaction capacity (MTA)	0.5	
Uptime (%)	95	
Utilization factor (%)	60 (oil production forecast)	
Overall plant fuel efficiency (%)	75	
Gas-Oil-Ratio (scf/bbl)	500	
Storage capacity (m3)	50,000	
Plant lifetime (yrs)	20	
Location	(Sub)-tropical	
Cost of feedstock (US$/MMBtu)	0	
IRR (after tax)	10	
Capex basis	LNG delivery FOB	
Results - Cost of Capacity (discounted)	**US$/MMBtu LNG**	**US$/bbl Oil**
Separate LNG vessel/GOR 500	3.08	1.10
Integrated Oil/LNG FPSO/GOR 500	2.02	0.72
Negative feedstock value @ **-0.04 US$/MMBtu**	0.00	0.00

For information please contact John J. Wollan, Acoustic Liquefaction Program Director, Cryenco, 3811 Joliet Street, Denver, Colorado 80239, U.S.A., Tel.: 1-303-371-6332, Fax: 1-303-371-0267, Email: johnw@cryenco.com or
Wim C. van Wijngaarden, Technology Manager Oil & Gas, Stork Engineers & Contractors, P.O. Box 152, 3100 AD Schiedam, The Netherlands, Tel.: 31-10-2986000, Fax: 31-10-2986050, Email: wc.van.wijngaarden@e-c.storkgroup.com